Research Note

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A STRAIN GAGE DIFFERENTIAL WEIGHING SYSTEM

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ABSTRACT

Explains the nature of strain, discusses several uses of strain gages, and describes the use of strain gages to measure loss or gain in weight of fuel beds in experimental burnings in the laboratory. Describes methods of installing strain gages for fire studies, and shows procedures for instrumentation and calibration.

Research projects at the Northern Forest Fire Laboratory have studied the influence of environmental conditions upon fire characteristics. The environmental conditions affect rate of spread, flame depth and length, rate of burning, and the radiant heat output. Methods and instrumentation were available to measure all of these parameters except rate of burning. Loss of weight in the fuel bed during a fire would indicate the rate of burning and give a measure of the rate of energy release. A weighing system was developed for recording the loss of weight of fuels burned in the wind tunnel and in the combustion laboratory.

The strain gage was selected as the sensing element for detecting weight change. After initial tests with cantilever beams proved unsatisfactory, force rings were used as the force-transferring mechanism. The transducers comprising force rings and strain gages allow continuous monitoring and recording, minimize frictional losses, and tend to compensate for side loading effects caused by poor alignment of the fuel bed on the weighing system.

WHAT STRAIN IS

Strain is a fundamental physical phenomenon.[1] It exists in solids at all times, due either to loads or to the weight of the material itself. The terms "strain" and "physical deformation" are synonymous. In engineering, "strain" refers to the change in any linear dimension of a body when a force is applied. Strain, as referred to above, is total strain, but of greater significance is unit strain. Average unit strain is the total deformation of a body in a given direction divided by the original length in that direction.

[1] Nalle, David H. Fundamentals of strain measurement and recording. Automatic Control 15(5): 51. 1961.

Strain equals the change in length divided by the original length. This change is very small and is expressed in microinches or millionths of an inch. Strain gages are electromechanical transducers that are attached to the surface of a structure. The general system is shown in figure 1.

The strain gage exhibits a change of electrical resistance with a change in strain. The change is linear and may be measured with suitable instrumentation. Although indirect, this method is precise. Sensitivity of a strain gage is determined by the electrical conductivity of the sensing element material and its configuration, and this is predetermined by the manufacturer. "Gage Factor" is a measure of strain gage sensitivity. All commercial resistance strain gages have a positive gage factor. This means that an increase in strain produces an increase in strain gage resistance.

In use, each portion of the strain gage is intimately bonded to the member being tested and accurately follows its movement under both tension and compression.

DESIRABLE CHARACTERISTICS OF STRAIN GAGES

An ideal universal strain gage would have the following characteristics:

1. Capability of measuring strains accurately under static or dynamic conditions.

2. Small size, light weight, and negligible thickness.

3. Suitability for remote observation and recording.

4. Resistance to influence of temperature, vibration, humidity, or other ambient conditions.

5. Ease of installation on member being analyzed.

6. Good stability and negligible hysteresis.

7. Large linear output in response to strain.

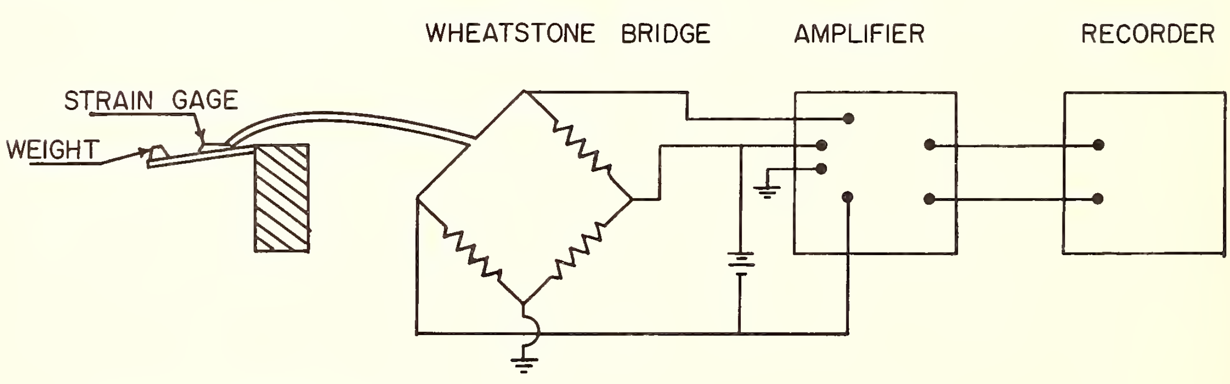


Figure 1.--A single gage configuration.

8. Low unit cost.

9. Dependability and resistance to aging or fatigue.

10. Capability of operating as an individual strain gage.

Etched foil strain gages.--Etched foil strain gages have practically all of these desirable characteristics. Several hundred different types and sizes are available commercially.

Temperature compensation.--Temperature compensation is one of the most important and one of the most frequently overlooked factors in strain measurement. It is possible to start out to measure strain and end up measuring ambient temperature changes because of the strain gage's sensitivity to temperature and to change in length.

Where transient temperature conditions are encountered, the best accuracy will be obtained by using temperature-compensated strain gages.

Many people mistakenly connect a single strain gage to a Wheatstone bridge with only two lead wires. Variation in ambient temperature introduces a variable resistance in one leg of the bridge that causes the measuring instrument to indicate a strain that does not exist. Using the Siemens three-lead method compensates for temperature variation in the leads.

In this three-lead method, two leads are in adjacent legs of the bridge. This cancels their resistance changes and does not disturb the bridge balance. The third lead is in series with the power supply and is, therefore, independent of bridge balance.

APPLICATION IN FIRE RESEARCH

Constantan foil, paper-base strain gages were used for some studies at the Northern Forest Fire Laboratory. The strain gages were mounted according to instructions enclosed with each packet of gages. These instructions must be followed closely to achieve good results. The gages were cemented to force rings made of 61S(6061) aluminum 1-5/8 inches in diameter and with 1/16-inch wall thickness; one gage was cemented to the inside (compression) and one

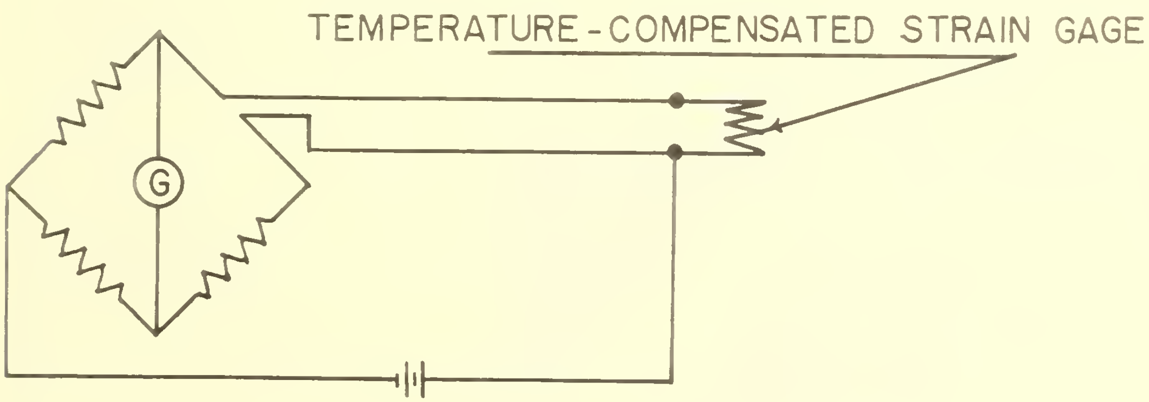


Figure 2.--Temperature-compensated three-lead wire system.

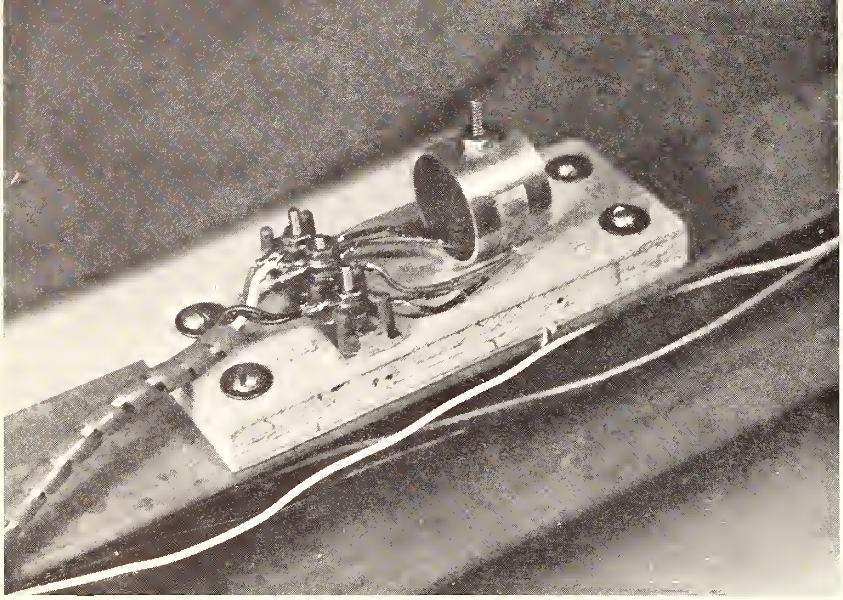


Figure 3.--Single force ring with two strain gages mounted on fuel bed support.

to the outside (tension) directly opposite each other (figs. 3 and 4). Four of these force rings were placed, one at each corner, under a fuel bed 8 feet long by 2 feet wide (figs. 5, 6, and 7). Although each force ring equipped with strain gages is temperature-compensated, when the four force rings are connected into the Wheatstone bridge, the total circuit does not have complete temperature compensation. This is probably due to slight differences between gages and temperatures at the four gage locations. To correct for temperature differences between locations, the force rings were enclosed in a masonite box painted with aluminum. A teflon cap was placed over the bolt stud and a plywood strip bolted to the metal crossarms to minimize heat conduction. To minimize changes induced by fluctuations in humidity, the strain gages were coated with a waterproofing wax.

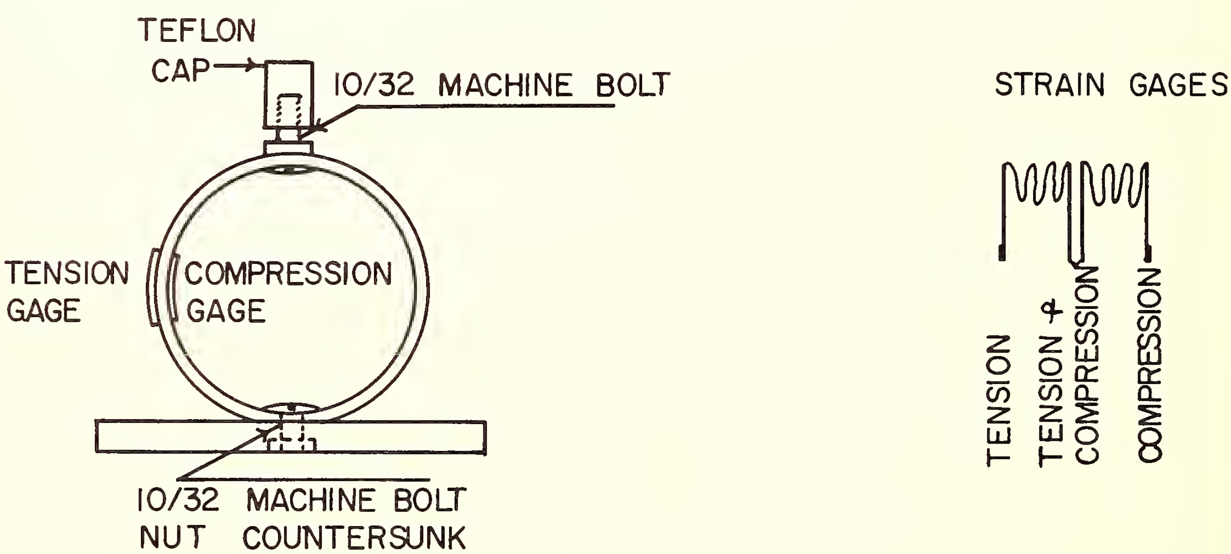


Figure 4. --Force ring configuration and strain gage electrical connection.

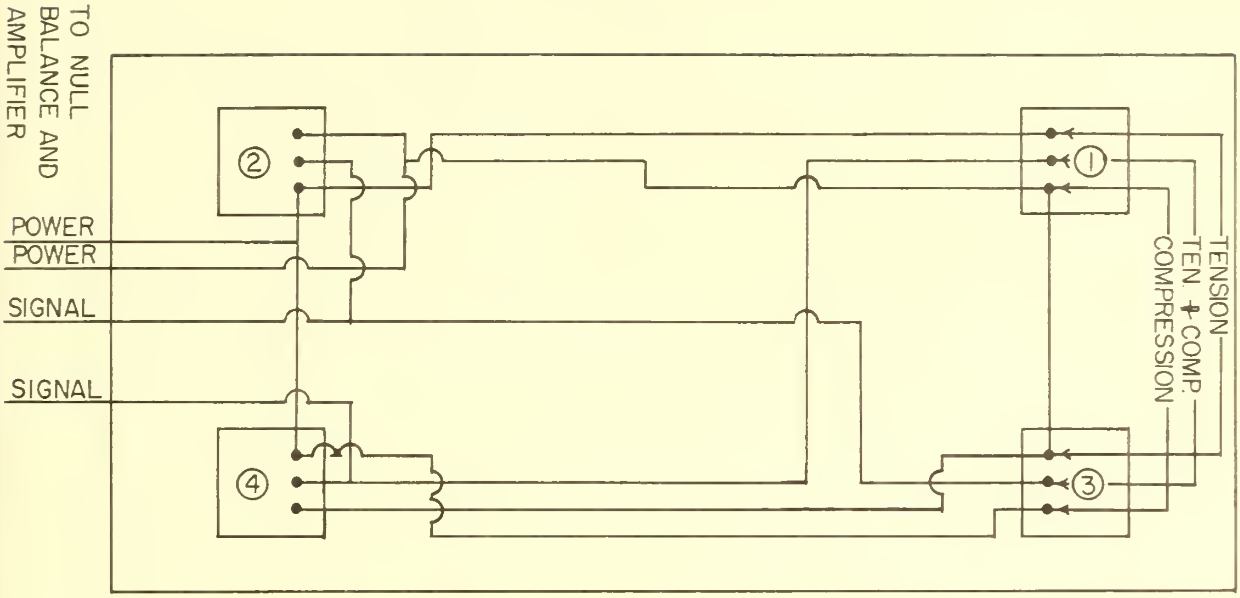
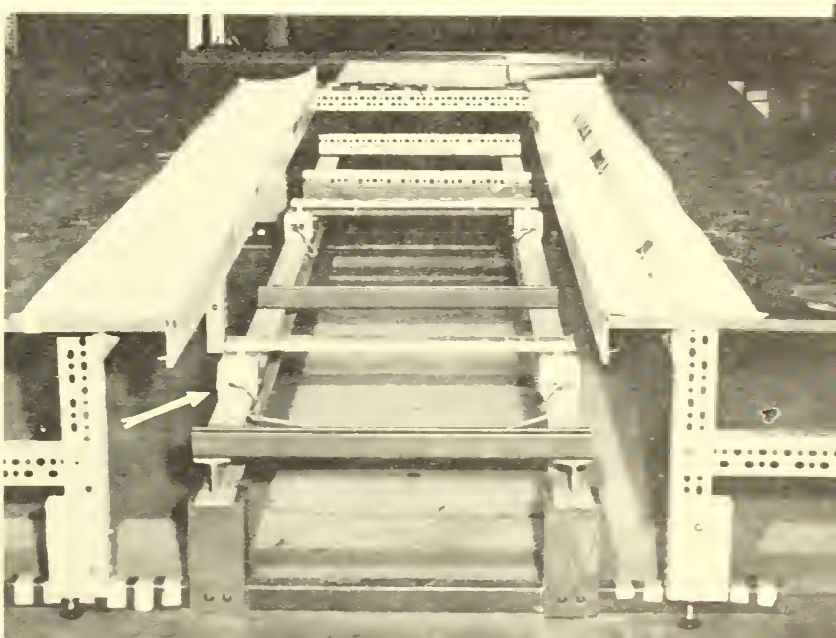


Figure 5.--Electrical schematic for strain gages under the fuel bed tray 8 feet long by 2 feet wide.

Each force ring was calibrated individually for sensitivity and checked for linearity and hysteresis. Linearity and hysteresis were very good and the sensitivity was as follows: (1) 5.13 µv/oz., (2) 4.75 µv/oz., (3) 6.26 µv/oz., and (4) 6.00 µv/oz., all with 6 volts excitation. The force rings were placed so that one of high sensitivity was diagonally opposite to one of low sensitivity. Linearity and hysteresis were checked by placing crossarms across a pair of force rings at each end of the fuel bed; these were interconnected with a crossbeam. Weights in 2-ounce increments up to 3 pounds were then placed on this crossbeam and the results were recorded (fig. 8). The crossbeam was removed, and a loaded fuel bed was then placed on the crossarms; weights in 4-ounce increments up to 3 pounds were then placed on the fuel bed and a calibration was made for 90 divisions on the recorder.

Figure 6.--Four force rings mounted on fuel bed support under aluminum painted boxes.



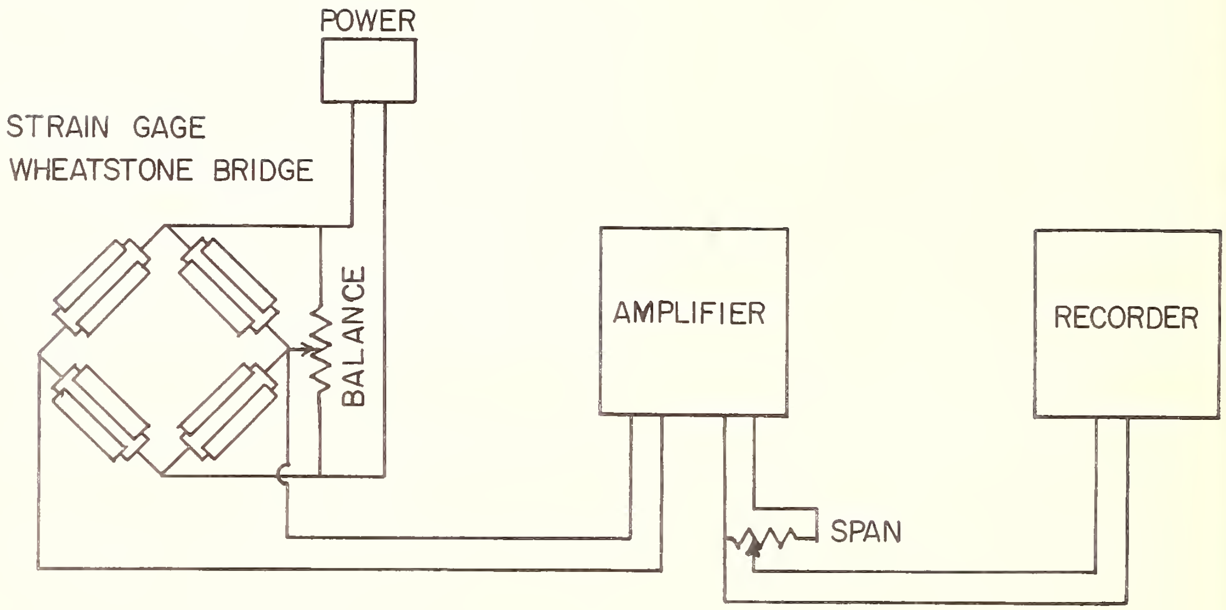


Figure 7.--Instrumentation layout for weight loss measuring system.

In operation, the weighing system provides a visual interpretation of the history of a burning operation. After ignition, a gradual buildup to a uniform burning rate may be observed. A flareup or suppression of flaming may be identified by the change in slope of the trace on the recorder. When the flame front has died out, the trace levels out and shows the gradual loss of weight due to afterburning. The average rate of weight loss is indicated by the slope of the line during the time in which the rate was stable.

This weighing system has had several useful applications. During tests of chemical fire retardants, it was used to monitor the loss of weight of moisture and to determine the proper drying conditions before experimental test burning of the fuel. The moisture content and response of a particular fuel type can be determined by using this strain gage weighing system. When a specific amount of fuel was ovendried and brought out to room temperature and room humidity, the weight change was recorded by this device. Also, fuel was placed in a covered container with a saturated sponge for a measured length of time before it was removed and the weight change recorded.

The burning characteristics of fuels can be evaluated when loading, compactness, and air supply rates are changed. A small fuel bed was weighed with a single transducer and changes in burning rate were recorded. Changes in burning rate could be equated to changes in any of several parameters (e.g., rate of spread, depth and length of flame, output of radiant heat, etc.).

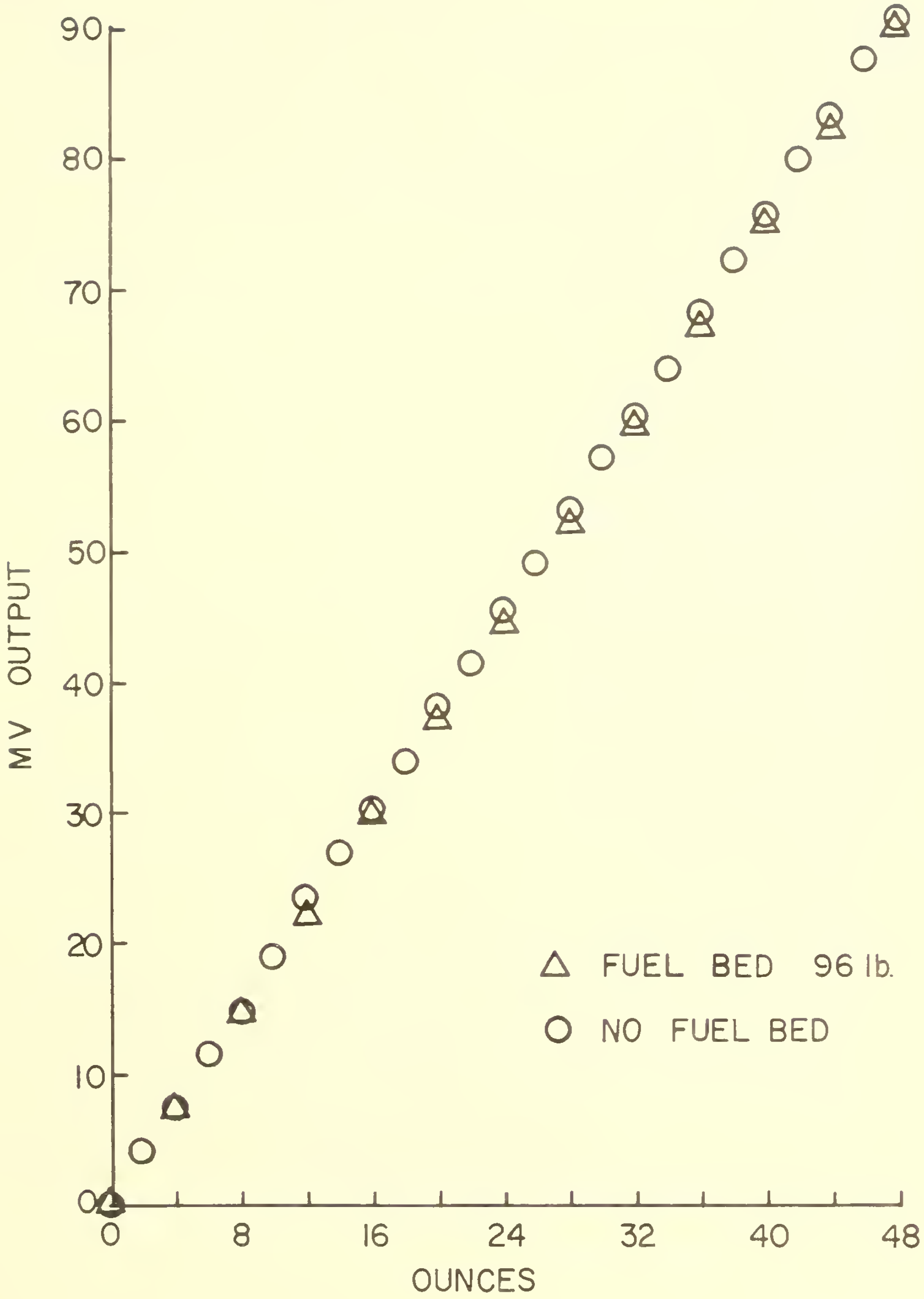


Figure 8.--Calibration comparison of a 96-pound load and no load.

CONCLUSIONS

It is possible to build a weighing system with strain gage transducers which is accurate and dependable, and provides a high sensitivity despite tare weights of 16 times the active load. The transducers are small and compact, and contain no moving parts. The output of the system is an electrical signal that can be recorded; this allows the rate of change of weight to be obtained. Strain gage measurements have proved to be reliable and valuable in studies of fire physics and fire behavior by determining change of weight in varied sizes of fuel samples.

These devices can also measure pressure, torque, force, stresses and strains with structures, and windspeed. Measurement of windspeed and direction can be made automatically with more complex arrangements of strain gages.

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